Ultra-Fast InfraRed Detector for Astronomy

Alessandro Drago (a), Emanuele Pace (b), Simone Bini (c), Mariangela Cestelli Guidi (c), Catalina Curceanu (c), Augusto Marcelli (c), Valerio Bocci (d)

(a) Università di Firenze & INFN/LNF, (b) Università di Firenze & OPC-Osservatorio Polifunzionale del Chianti, (c) INFN/LNF, (d) INFN/Roma1

Frontier Detector for Frontier Physics - 15th Pisa Meeting on Advanced Detectors, La Biodola, Isola d'Elba, 22-28 May 2022

INTRODUCTION

The detection of the first gravitational wave in 2015 by the LIGO-VIRGO collaboration has opened a new era for the astronomy that, after this event, can correlate even more types of signals from the space. Indeed, two years later, the record of the gravitational wave GW170817 of the merger of two neutron stars, has found simultaneous electromagnetic signal counterparts. One was from the FERMI-GRST (FERMI Gamma-Ray Space Telescope), where the GRB170817A gamma-ray burst recorded the first multi-messenger transient. The multi-messenger astronomy is a new and very interesting approach to have a more complete and deeper vision of the universe. The goal of this philosophy is to evaluate how the synchronized arrival of quite different signals from the same astronomical source can give us a more detailed description of the events. Focusing on the photon detection, different technologies are necessary for observing remote sources in γ or X rays, UV or visible, infrared, micro or radio waves. Considering the infrared detection, some telescopes are for satellites, like JWST (James Webb Space Telescope), that is going to start to take data in 2022, and WISE, while others are ground-based, like three infrared recent instruments: VIRCAM (the VISTA InfraRed Camera), MOONS (The Multi-Object Optical and Near-infrared Spectrograph) and ERIS-NIX, both by ESO's Very Large Telescope (VLT). All these detectors are mainly designed for working "transversally" that is to get still images and spectrographs. But, if we consider the FERMI-GRST, the telescope is made by two independent instruments, the LAT(Large Area Telescope) for working transversally, and the GBM (Gamma-Ray Burst Monitor) for working longitudinally (i.e. in time), in such a way making possible to search fast transient [1], even on the μs scale (fig.1).

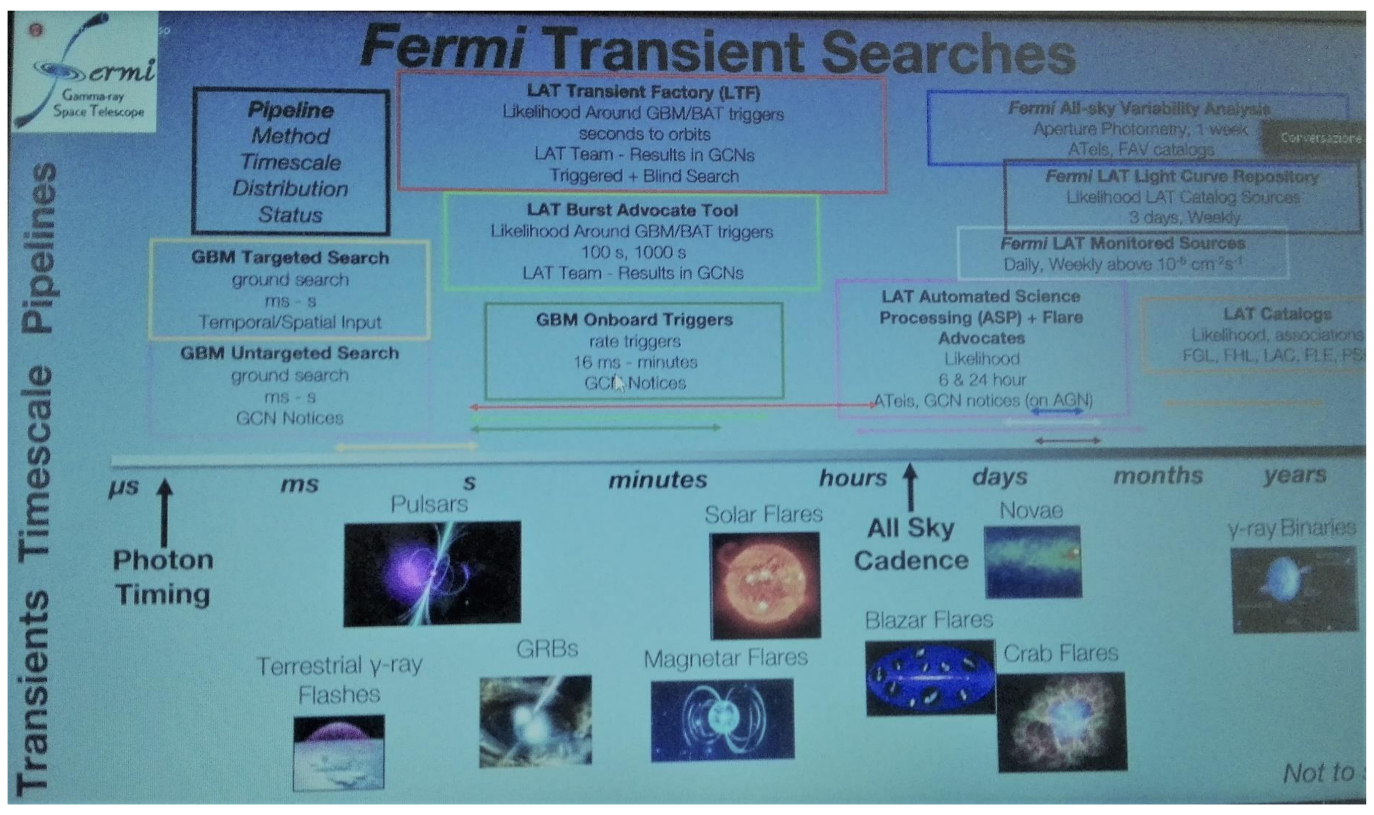


Fig.1 Fermi Transient Search proposed by J.Racusin (NASA) in a recent talk [1]. The transient time scale goes from the μs to the years.

Longitudinal IR detection in lepton circular accelerators

In order to search fast transients in the infrared astronomy with the temporal scale of the GBM and the FRB (Fast Radio Burst) ones, an ultra fast IR longitudinal detector has been designed to be used with a ground-based telescope. It is necessary to consider that the search will consist in faint and rare events, indeed for example the number of γ bursts observed by Fermi in more than 10 years is 2677 and only twice 5 flashes were observed in the same day. A useful way to proceed could be to take advantage of the experience done in circular accelerators. As it is well known in a storage ring the electrons and the positrons lose energy in every turn for synchrotron acceleration. Giving that the particles are gathered in bunches by the radiofrequency field restoring the lost energy, also the synchrotron light is pulsed with the same period. The 3+L and 3L2D INFN experiments[2] carried out at Sinbad, the DAFNE infrared beamline, have demonstrated the feasibility of ultra fast IR bunch-by-bunch detectors able to acquire signals with rise time of the order of 1 ns. Two plots recorded by 3+L/3L2D team are shown below in the Fig. 2 and 3.

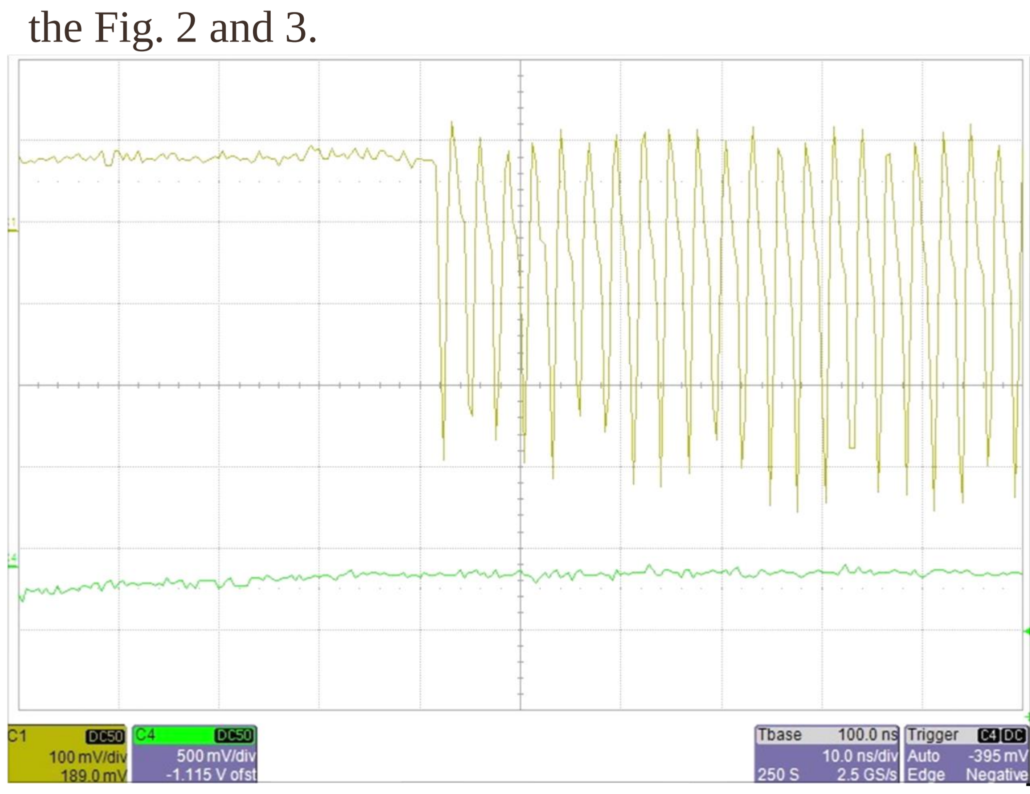


Fig.2 the IR pulsed light converted in electrical signal and acquired by the oscilloscope. The bunch distance is 2.7 ns. Rise time is ~1 ns.

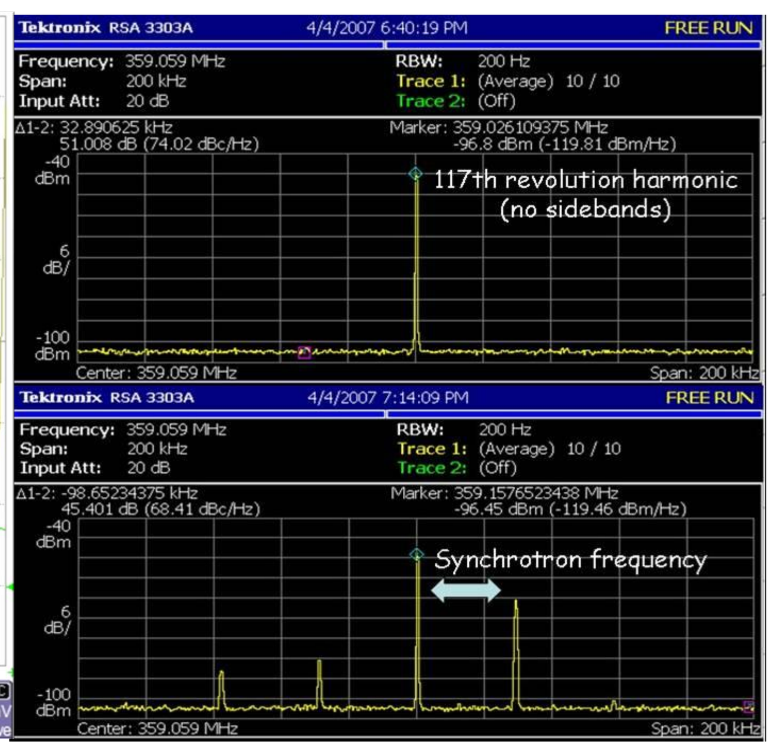


Fig.3 shows the FFT of the IR signal after a transient due to the feedback turning on/off that change the beam dynamics.

FaIrTel, a FAst InfraRed TELescope detector

The FAIRTEL (FAst InfraRed ground-based TELescope) experiment has been partially funded for the year 2022 by CSNV of INFN to design a detector able to study ultra-fast transients as well as slower time variations of signals in the infrared astronomy. Observations on astrophysical signals with fast transient present more promising and exciting cases every day, as demonstrated for gamma ray bursts/flares or for the fast radio bursts. The FAIRTEL detector can explore astronomical sources in the mid-IR by interfacing a ground-based reflecting telescope. The detector design is based on the experience previously done at Sinbad by 3+L and 3L2D by using HgCdTe semiconductors made by Vigo System S.A (Poland) [3]. Nevertheless, important differences must be considered given that astronomy and stored beam signals differ in many features. First, the detection circuit need to work with a larger range starting from extremely low frequencies. This feature is not necessary in the beam diagnostics that can use RF amplifiers with band > 0.1 MHz. A second necessary feature consists in obtaining the "dark" signal in real time in order to subtract it from the astronomical signal. Hence the philosophy of the proposed detector consists in observing the IR signal longitudinally (which means recording time tracks) rather than transversely (which means taking pictures) as it is usually done. In the first phase only one pixel will be implemented for the signal and another one for the "dark". In a second phase, if a larger budget will be approved, up to 19 pixels will be loaded in the board (7 for the astronomical signal and 12 for the "dark"). In fig. 4 the HgCdTe component implemented in the circuit is shown and in the fig. 5 the responsivity vs. the wavelength are plotted.

Fig. 4 (on the right) the VIGO HgCdTe component mechanical Features. Note that the aperture angle is 90 degrees.

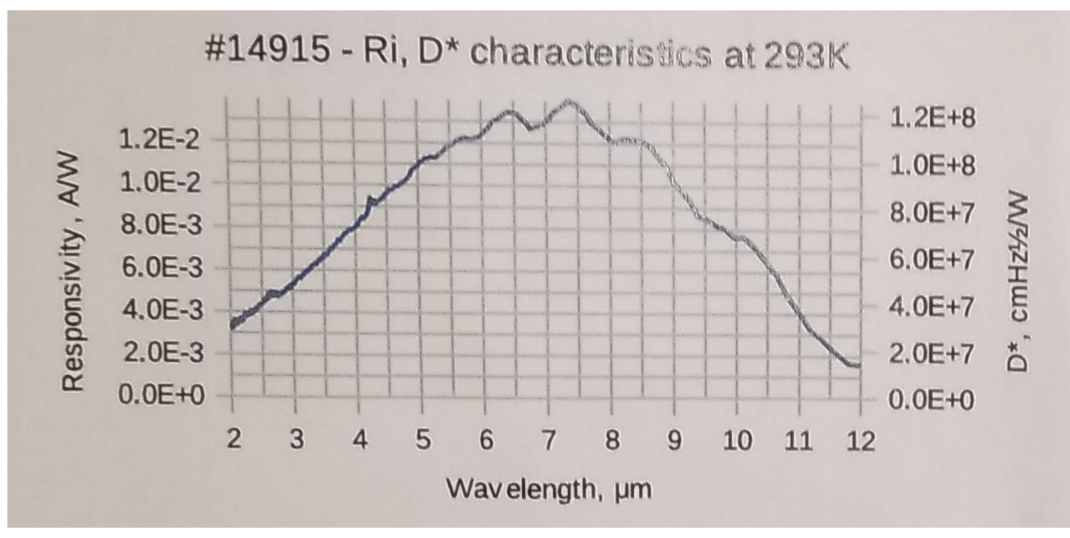
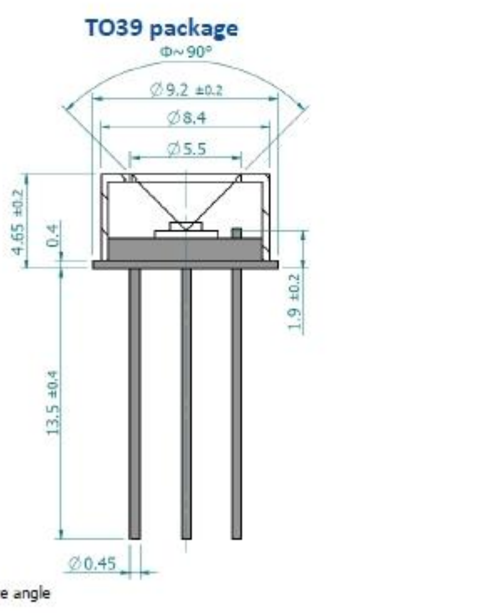


Fig. 5 plots responsivity (A/W) vs. wavelength (μm)



To implement the detector, a pcb (printed circuit board) has been designed for the fabrication. It has cellular phone dimensions (14x7cm) to be easily grabbed by low-cost accessory used for amateur telescopes. The pcb will be loaded with the pixels (2 at the begin, then up to 19) on one side (in fig. 6 on the left): white inner pixels for the signal, outer pixels for the "dark" reference. The other components and connectors will be loaded on the other side of the board (on the right in the fig. 6). The pcb has 3+3 outputs: signal and dark for low frequency, for high frequency and for DC-high frequency. Single pixel output is also possible. The digital acquisition system will be done by an oscilloscope in phase 1 and by ARDU-SIPM [4],[5] compact data acquisition system in phase 2.

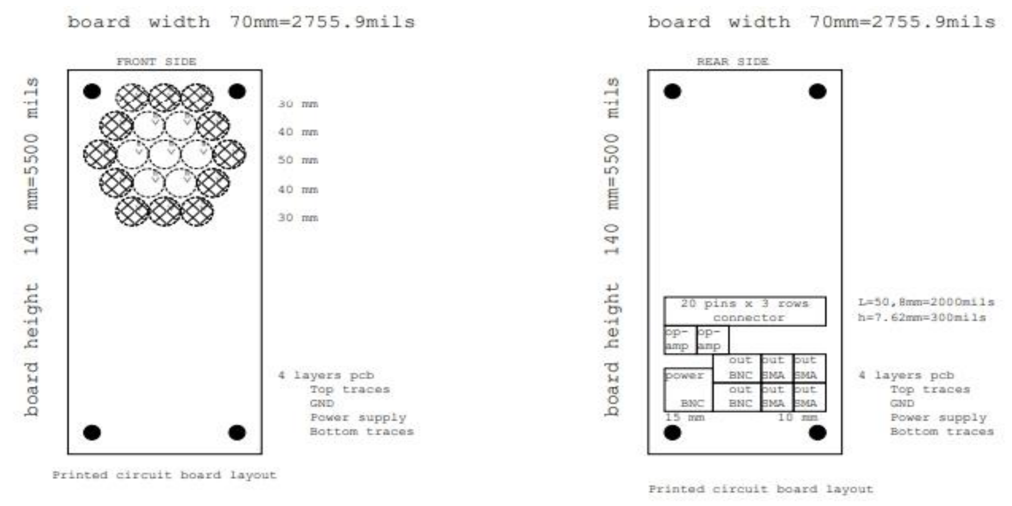


Fig.6 shows the two sides of the pcb in cellular format

Fig.7 shows the digital acquisition system ARDU-SIPM developed by INFN-RM1.

CONCLUSIONS

In order to acquire fast astronomical signals, after the tests at the Sinbad beamline, the detector will be brought to the OPC (Osservatorio Polifunzionale del Chianti, see picture below) to be interfaced with the reflecting telescope type Ritchey Cretien with 80 cm diameter.

REFERENCES

[1] Judith Racusin (NASA's Goddard Space Flight Center), "Surveying the Dynamic Universe with the Fermi Gamma-ray Space Telescope", L'Aquila Joint Astroparticle Colloquium, 4/27/22

[2] Alessandro Drago et al., "Fast Rise Time IR Detectors for Lepton Colliders". Invited presentation at 4th ICFDT 2016, 31/3/2016. Published in JINST 11 (2016) no.07, C07004.

[3] https://vigo.com.pl/en/home/

[4] https://www.seti.net/cosmic-rays/ArduSiPM%20paper%20-%20V%20Bocci.pdf

[5] V. Bocci, "Compact and Light All-in-One Detectors for space application", in this workshop.

Contact alessandro.drago@unifi.it
Alessandro.Drago@lnf.infn.it

Osservatorio Polifunzionale Del Chianti

UNIVERSITÀ DEGLI STUDI FIRENZE

INFN